Anatomically considered, fast soft-tissue simulation for cranio-maxillofacial surgery

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INTRODUCTION

There have been increasing demands for predicting post-operative soft-tissue changes in a computer-assisted cranio-maxillofacial planning. Some commercial software solutions have been developed for simulating post-operative soft-tissue variations, but most of them fail to realize delicate soft-tissue changes around lips and nose area, which are the error-sensitive regions for surgeons. Some research tools can realize these kinds of subtle changes, however the long calculation time and laborious pre-processing procedures make these solutions hard to be integrated into clinical practice. To overcome these limitations, we propose a computationally efficient, bio-mechanically relevant soft-tissue simulation method driven by patient-specific anatomy. The proposed method can be seamlessly integrated into the clinical workflow without requiring additional image modality like MRI.

MATERIALS AND METHODS

Two clinical CT scans (bi-maxillary osteotomy cases : LeFort I and LeFort III) were used for validating this study. We performed manual segmentation of extra-cranial soft-tissue using commercial software (Amira, Mercury Computer Systems, Berlin, Germany). Then tetrahedral volumetric mesh model was generated. Since it is difficult to identify facial muscles from conventional CT scan, we propose to construct patient-specific muscles by morphing anatomical structures from a facial atlas model [Smith2007], using landmark-based thin-plate-spline (TPS) deformation. To incorporate anisotropy of facial muscles, we extracted the direction of the muscles by constructing oriented-bounding box (OBB). Finally, material properties were assigned considering the proportion and direction of the muscle in each tetrahedron.

We adopted mass-tensor model (MTM) for simulation [Delingette2004], which can be regarded as localized finite-element model (FEM). Mechanical simulations using MTM were compared with that of commercial FEM software (Abaqus/CAE 6.7, Dassault Systems) and real post-operative scans. The surface-to-surface distance was measured for accuracy assessment.

RESULTS AND DISCUSSION

The average distance error between MTM and FEM simulations was 0.023mm$\pm$0.0061mm. The MTM calculation was almost 40 times faster than FEM. (MTM: 4.5 sec, FEM: 186 sec)

However, there were significant differences with real post-operative data. For LeFort III case, large errors (>10mm) around eyes were observed. This might be caused by incomplete segmentation and boundary condition on this area. For LeFort I case, large erroneous regions around cheeks occurred due to post-operative swelling. Post-operative CT scans in good conditions will be desired. And the validity of muscle morphing needs to be investigated with reference MRI data.

REFERENCES

1. Smith et al, Plastic and Reconstruction Surgery, 120(6):1641-1646, 2007.
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